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Lee

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(54) **METHOD AND APPARATUS FOR ESTIMATING A GAIN OF A CHANNEL IN A WIRELESS NETWORK**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 144 days.

This patent is subject to a terminal disclaimer.

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(22) Filed: **Apr. 13, 2015**

Related U.S. Application Data

(63) Continuation of application No. 13/951,003, filed on Jul. 25, 2013, now Pat. No. 9,007,950, which is a continuation of application No. 13/596,536, filed on Aug. 28, 2012, now Pat. No. 8,498,637, which is a continuation of application No. 12/128,048, filed on May 28, 2008, now Pat. No. 8,254,911.

(60) Provisional application No. 60/941,818, filed on Jun. 4, 2007.

(51) **Int. Cl.**

H04L 1/00	(2006.01)
H04J 11/00	(2006.01)
H04W 24/08	(2009.01)
H04L 5/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H04J 11/005*** (2013.01); ***H04L 5/0032*** (2013.01); ***H04L 5/0048*** (2013.01); ***H04W 24/08*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 17/00; H04B 3/46; H04B 7/2121; H04B 7/2123; H04B 7/2618; H04L 43/00; H04L 43/50; H04W 24/00; H04W 72/04; H04W 72/12; H04W 76/00; H04W 72/0446; H04W 88/02; H04J 2203/0069; H04Q 2213/394; H04M 1/24; H04M 1/72519
USPC 370/252, 329, 336; 455/67.11, 425, 450, 455/452
See application file for complete search history.

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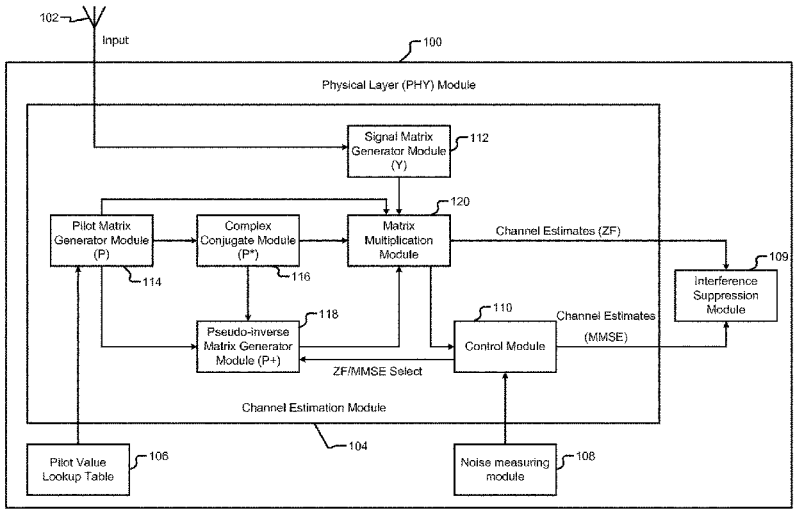
U.S. Appl. No. 12/128,048, filed May 28, 2008.
U.S. Appl. No. 13/596,536, filed Aug. 28, 2012.
U.S. Appl. No. 13/951,003, filed Jul. 25, 2013.

Primary Examiner — Dady Chery

(57) **ABSTRACT**

A physical layer (PHY) device including a first module and a second module. The first module is configured to (i) measure noise based on signals received by the PHY device via a channel and (ii) generate information in response to measuring the noise based on the signals received by the PHY device via the channel. The second module is configured to determine, depending on whether the first module is able to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel, whether to estimate a gain of the channel using (i) a first procedure to estimate the gain of the channel or (ii) a second procedure to estimate the gain of the channel.

20 Claims, 10 Drawing Sheets



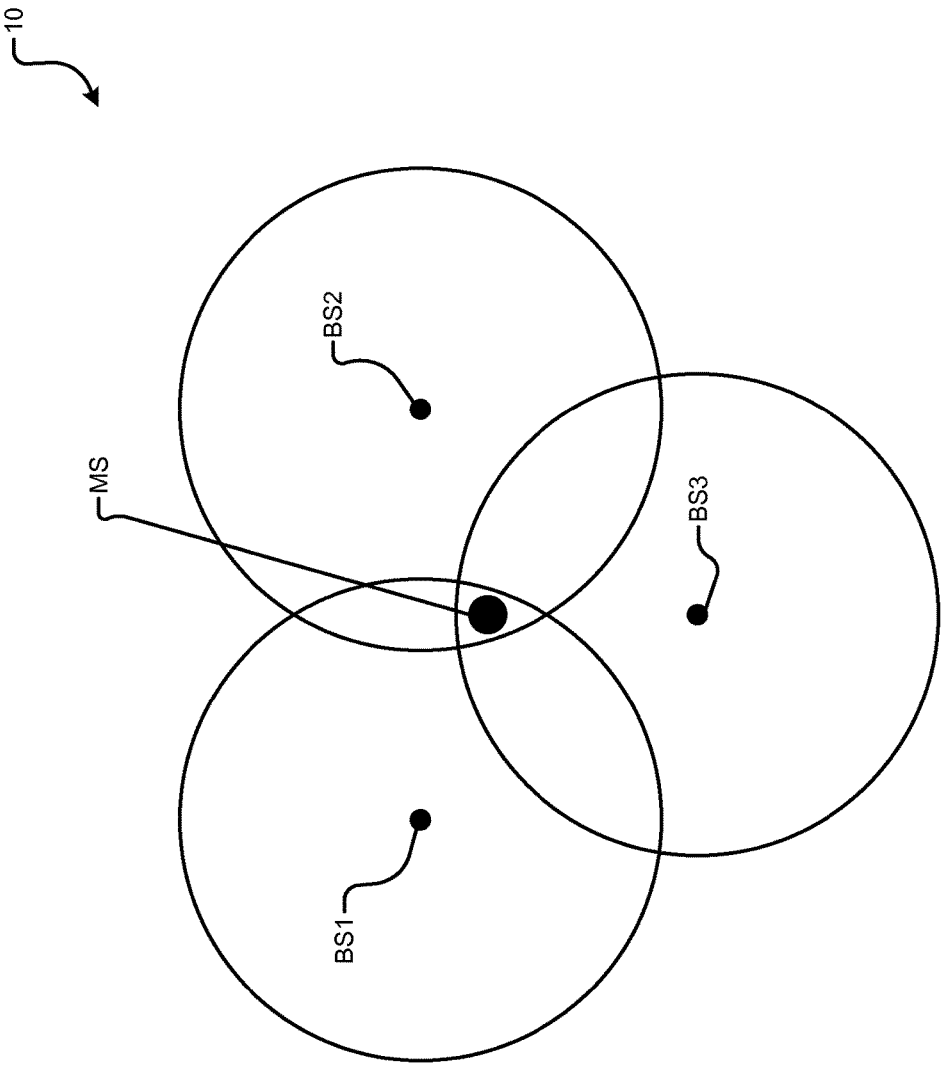


FIG. 1A
Prior Art

FIG. 1B
Prior Art

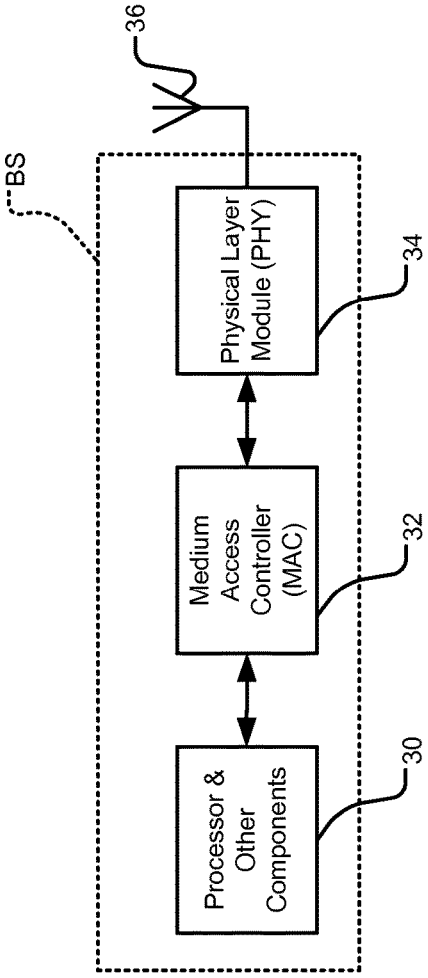
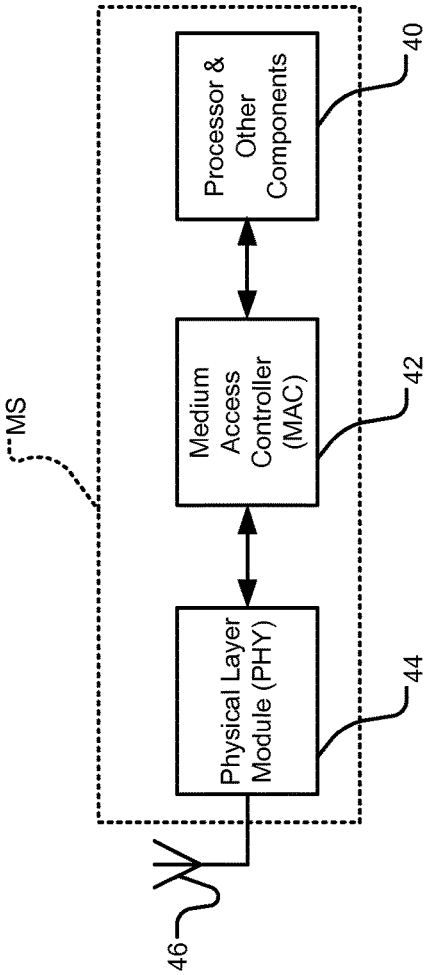


FIG. 1C
Prior Art



	P1	P2	P3
BS1	± 1	0	0
BS2	0	± 1	0
BS3	0	0	± 1

FIG. 2A

	P1	P2
BS1	1	1
BS2	1	- 1

FIG. 2B

	P1	P2	P3
BS1	- 1	0	0
BS2	0	1	0
BS3	0	0	- 1
	Y[1]	Y[2]	Y[3]

FIG. 3

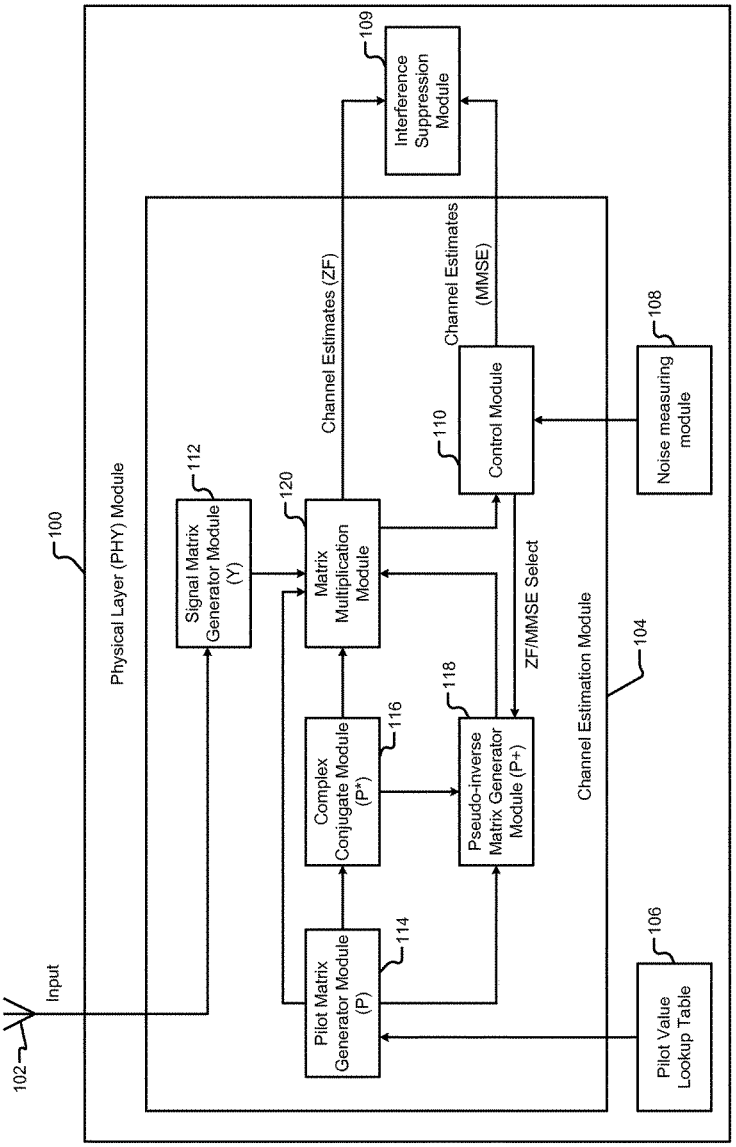

102
Input
100
Physical Layer (PHY) Module
Signal Matrix Generator Module (Y)
112
Pilot Matrix Generator Module (P)
114
Complex Conjugate Module (P*)
116
Pseudo-inverse Matrix Generator Module (P+)
118
Matrix Multiplication Module
120
Channel Estimates (ZF)
Channel Estimates (MMSE)
ZF/MMSE Select
Channel Estimation Module
104
Interference Suppression Module
109
Control Module
110
Noise measuring module
108
Pilot Value Lookup Table
106

FIG. 4A

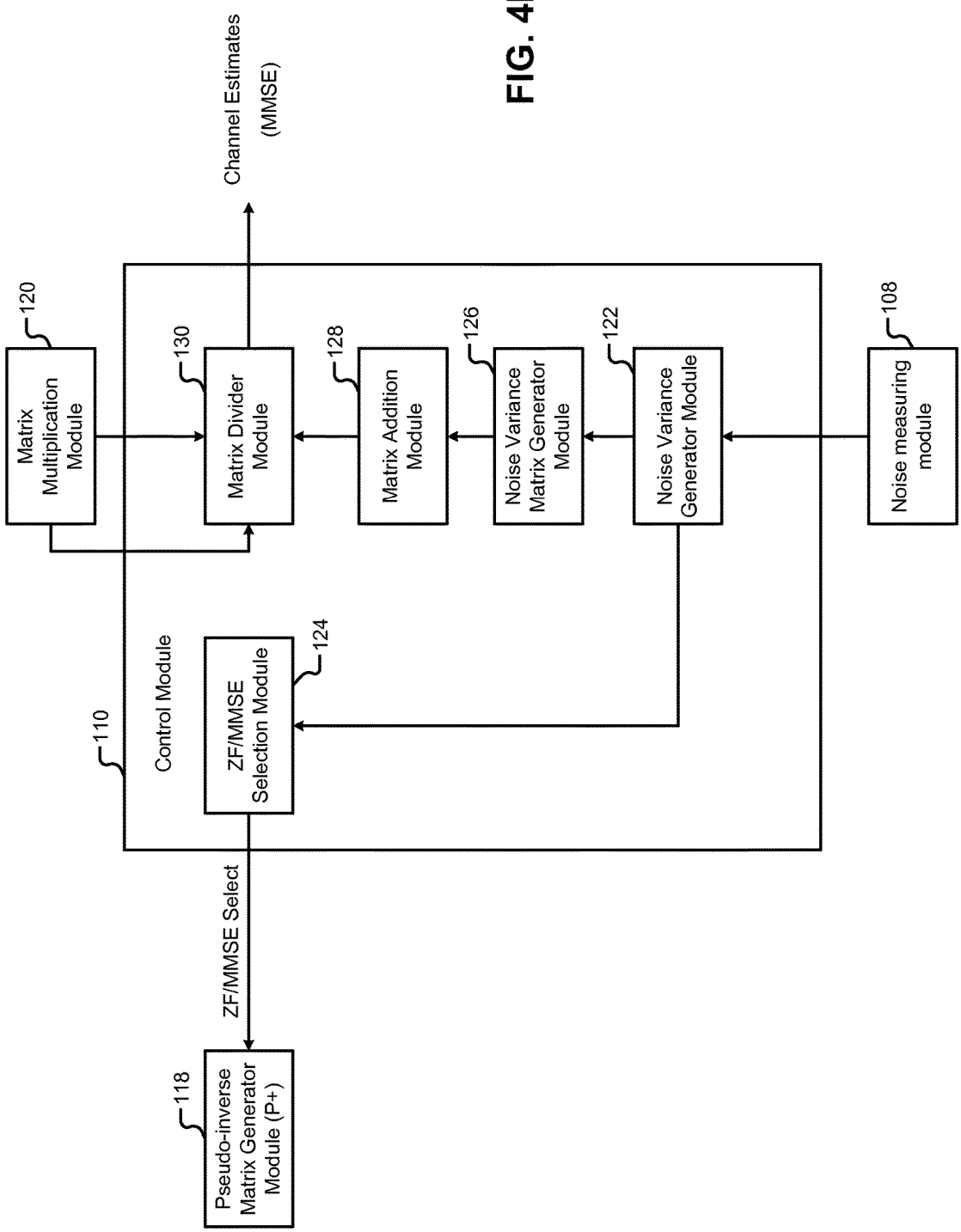
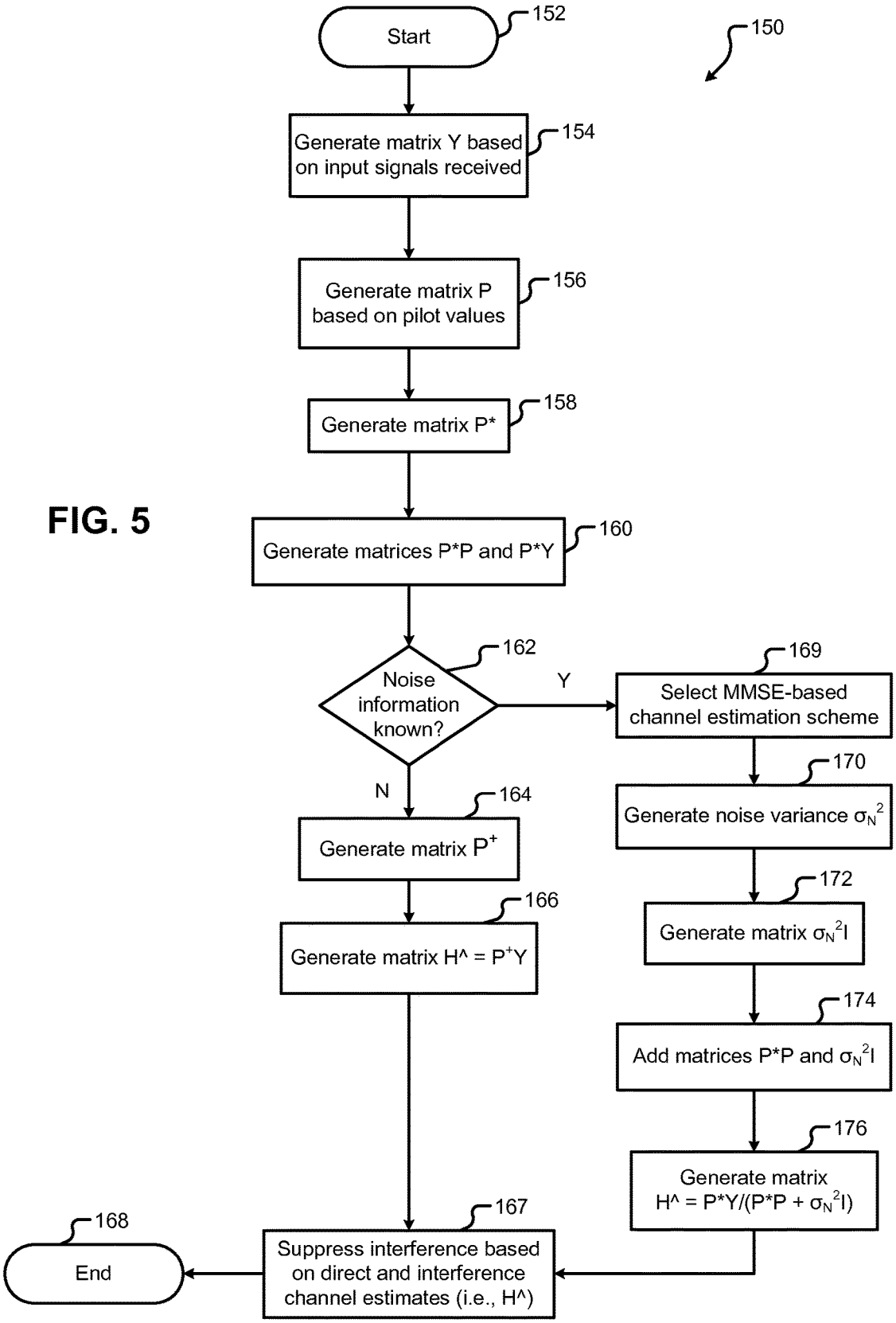

Channel Estimates (MMSE)
120
Matrix Multiplication Module
130
Matrix Divider Module
128
Matrix Addition Module
126
Noise Variance Matrix Generator Module
122
Noise Variance Generator Module
108
Noise measuring module
110
Control Module
124
ZF/MMSE Selection Module
ZF/MMSE Select
118
Pseudo-inverse Matrix Generator Module (P+)

FIG. 4B

FIG. 5


Start
152
150
Generate matrix Y based on input signals received
154
Generate matrix P based on pilot values
156
Generate matrix P*
158
Generate matrices P*P and P*Y
160
Noise information known?
162
Y
N
Select MMSE-based channel estimation scheme
169
Generate noise variance σ_N^2
170
Generate matrix $\sigma_N^2 I$
172
Add matrices P*P and $\sigma_N^2 I$
174
Generate matrix H^ = P*Y/(P*P + $\sigma_N^2 I$)
176
Generate matrix H^ = $P^+ Y$
166
Generate matrix P^+
164
Suppress interference based on direct and interference channel estimates (i.e., H^)
167
End
168

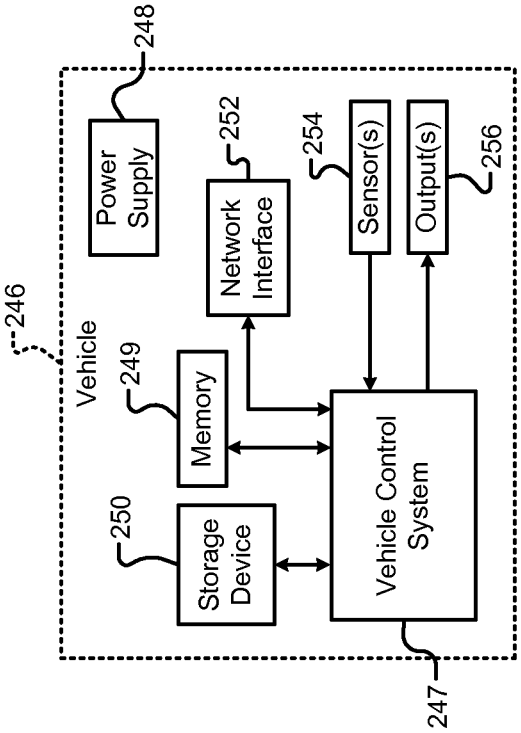

246
Vehicle
248
Power Supply
252
Network Interface
254
Sensor(s)
256
Output(s)
249
Memory
250
Storage Device
Vehicle Control System
247

FIG. 6A

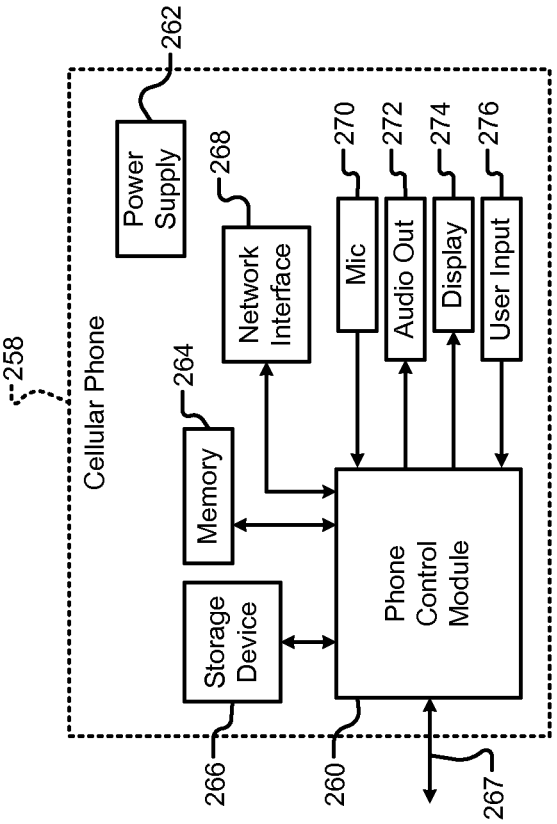

258
Cellular Phone
262
Power Supply
268
Network Interface
270
Mic
272
Audio Out
274
Display
276
User Input
264
Memory
Storage Device
Phone Control Module
266
260
267

FIG. 6B

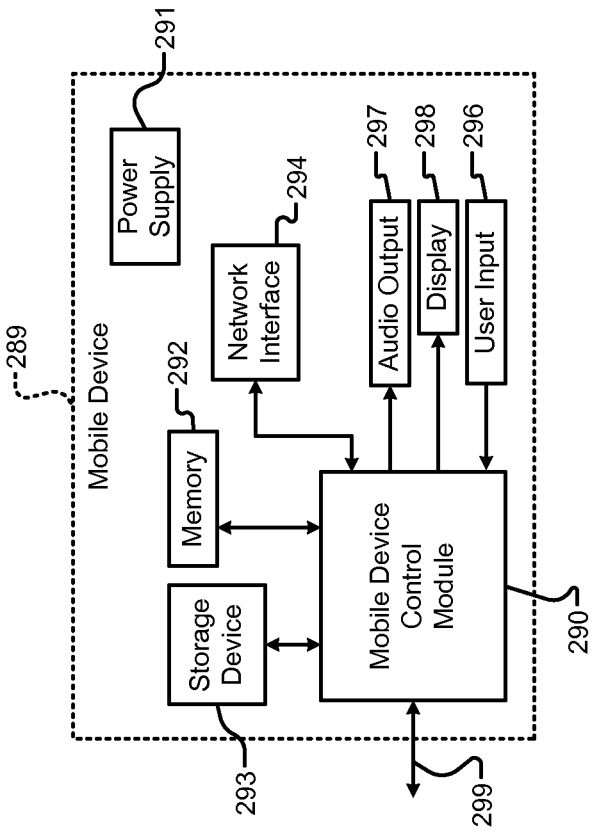

289
Mobile Device
291
Power Supply
294
Network Interface
292
Memory
Storage Device
293
Mobile Device Control Module
290
297
Audio Output
298
Display
296
User Input
299

FIG. 6C

METHOD AND APPARATUS FOR ESTIMATING A GAIN OF A CHANNEL IN A WIRELESS NETWORK

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. patent application Ser. No. 13/951,003 (now U.S. Pat. No. 9,007,950), filed Jul. 25, 2013 which is a continuation of U.S. patent application Ser. No. 13/596,536 (now U.S. Pat. No. 8,498,637), filed on Aug. 28, 2012, which is a continuation of U.S. patent application Ser. No. 12/128,048 (now U.S. Pat. No. 8,254,911), filed on May 28, 2008, which claims the benefit of U.S. Provisional Application No. 60/941,818, filed on Jun. 4, 2007. The entire disclosures of the above applications are incorporated herein by reference.

FIELD

The present disclosure relates to communication systems, and more particularly to estimating direct and interference channels in cellular communication systems.

BACKGROUND

The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent the work is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

Referring now to FIGS. **1**A-**1**C, cellular communication systems (hereinafter cellular systems) typically comprise multiple base stations and mobile stations. In FIG. **1**A, an exemplary cellular system **10** comprising base stations BS**1**, BS**2**, and BS**3** (collectively BS) and a mobile station (MS) is shown. In FIG. **1**B, each BS may comprise a processor **30**, a medium access controller (MAC) **32**, a physical layer (PHY) module **34**, and an antenna **36**. In FIG. **1**C, the MS may comprise a processor **40**, a MAC **42**, a PHY module **44**, and an antenna **46**. The PHY modules **34** and **44** may comprise radio frequency (RF) transceivers (not shown) that transmit and receive RF signals via the antennas **36** and **46**, respectively.

The BSs and the MS may transmit and receive signals while the MS moves relative to the BSs. Consequently, the MS may receive signals transmitted by one or more BSs depending on the location of the MS relative to the BSs. For example, the MS may receive signals transmitted by BS**1**, BS**2**, and BS**3** when the MS is located as shown in FIG. **1**A.

Typically, the BSs use the same channel, frequency, and time slot to transmit signals. The MS may associate with a BS called a serving BS and receive signals transmitted by the serving BS. A channel of signals received by the MS from the serving BS is called a direct channel. Additionally, the MS may receive signals transmitted by one or more neighboring BSs. A channel of signals received by the MS from a neighboring BS is called an interference channel.

When the MS is associated with the serving BS, the signals received by the MS from the neighboring BSs may interfere with the signals received by the MS from the serving BS. The resulting interference is called inter-cell co-channel interference (hereinafter interference). The quality of communication between the MS and the serving BS may degrade more due to the interference than due to noise when cell size decreases.

To reduce the interference, most cellular systems use different frequencies, time slots, or codes to transmit signals from different BSs so that the signals transmitted by multiple BSs are almost orthogonal to each other. Since cross-correlation between signals that are almost orthogonal is nearly zero, the interference between the signals is reduced.

For example, systems utilizing Orthogonal Frequency Division Multiplexing Access (OFDMA) use pilot tones that are almost orthogonal, and systems utilizing Code Division Multiple Access (CDMA) use codes that are almost orthogonal. In the OFDMA systems, the pilot tones are generated using pseudo-random noise (PN) sequences. The PN sequences, however, may have some non-zero cross-correlation. Consequently, the pilot tones may not be perfectly orthogonal, and some interference may persist. Similarly, some interference may persist in CDMA systems when the codes are not perfectly orthogonal.

SUMMARY

A mobile station (MS) comprises an input and a channel estimation module. The input receives signals from N base stations (BSs), where N is an integer greater than 1. The N BSs include a serving BS of the MS and (N−1) neighboring BSs. Each of the N BSs uses at least N pilot values to transmit the signals. One of the signals having a direct channel gain (direct channel) is transmitted by the serving BS. Others of the signals having (N−1) interference channel gains (interference channels) are transmitted by the (N−1) neighboring BSs. The channel estimation module generates channel estimates of the direct channel and the (N−1) interference channels based on the N pilot values when the MS is associated with the serving BS.

In other features, the N pilot values are generated based on sequences having a non-zero cross-correlation. The N pilot values are decoded from one of a preamble sequence and a DL-MAP transmitted by the N BSs.

In another feature, the channel estimation module generates a first matrix based on the signals, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the channel estimation module generates a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the channel estimation module generates a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the MS further comprises an interference suppression module that suppresses inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the other signals interfere with the signal.

In another feature, the MS further comprises antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and that receive the signals via at least one of the antennas.

In another feature, the MS and the N BSs communicate via a cellular communication system that includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a method comprises associating a mobile station (MS) with one of N base stations (BSs), where N is an integer greater than 1. Each of the N BSs uses at least N pilot values when communicating with MSs. The method further comprises receiving a signal having a direct channel gain (direct channel) from one of the N base stations (BSs) via an input of the MS. The method further comprises receiving signals having interference channel gains (interference channels) from others of the N BSs via the input. The method further comprises generating channel estimates of the direct channel and the interference channels based on the N pilot values when the MS is associated with one of the N BSs.

In another feature, the method further comprises generating the N pilot values based on sequences having a non-zero cross-correlation.

In another feature, the method further comprises decoding the N pilot values from one of a preamble sequence and a DL-MAP transmitted by the N BSs.

In another feature, the method further comprises generating a first matrix based on the signal received from one of the N BSs and the signals received from the others of the N BSs, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the method further comprises generating a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the method further comprises generating a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the method further comprises suppressing inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the signals received from the others of the N BSs interfere with the signal received from one of the N BSs.

In another feature, the method further comprises providing antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and receiving the signal from one of the N BSs and the signals from the others of the N BSs via at least one of the antennas.

In other features, the method further comprises communicating with the MS and the N BSs via a cellular communication system. The cellular communication system includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a mobile station (MS) comprises input means for receiving signals from N base stations (BSs), where N is an integer greater than 1. The N BSs include a serving BS of the MS and (N−1) neighboring BSs. Each of the N BSs uses at least N pilot values to transmit the signals. One of the signals having a direct channel gain (direct channel) is transmitted by the serving BS. Others of the signals having (N−1) interference channel gains (interference channels) are transmitted by the (N−1) neighboring BSs. The MS further comprises channel estimation means for generating channel estimates of the direct channel and the (N−1) interference channels based on the N pilot values when the MS is associated with the serving BS.

In other features, the N pilot values are generated based on sequences having a non-zero cross-correlation. The N pilot values are decoded from one of a preamble sequence and a DL-MAP transmitted by the N BSs.

In another feature, the channel estimation means generates a first matrix based on the signals, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the channel estimation means generates a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the channel estimation means generates a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the MS further comprises interference suppression means for suppressing inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the other signals interfere with the signal.

In another feature, the MS further comprises antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and that receive the signals via at least one of the antennas.

In another feature, the MS and the N BSs communicate via a cellular communication system that includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a computer program stored on a computer readable medium and executed by a processor comprises associating a mobile station (MS) with one of N base stations (BSs), where N is an integer greater than 1. Each of the N BSs uses at least N pilot values when communicating with MSs. The computer program further comprises receiving a signal having a direct channel gain (direct channel) from one of the N base stations (BSs) via an input of the MS. The computer program further comprises receiving signals having interference channel gains (interference channels) from others of the N BSs via the input. The computer program further comprises generating channel estimates of the direct channel and the interference channels based on the N pilot values when the MS is associated with one of the N BSs.

In another feature, the computer program further comprises generating the N pilot values based on sequences having a non-zero cross-correlation.

In another feature, the computer program further comprises decoding the N pilot values from one of a preamble sequence and a DL-MAP transmitted by the N BSs.

In another feature, the computer program further comprises generating a first matrix based on the signal received from one of the N BSs and the signals received from the

others of the N BSs, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the computer program further comprises generating a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the computer program further comprises generating a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the computer program further comprises suppressing inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the signals received from the others of the N BSs interfere with the signal received from one of the N BSs.

In another feature, the computer program further comprises communicating with antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and receiving the signal from one of the N BSs and the signals from the others of the N BSs via at least one of the antennas.

In other features, the computer program further comprises communicating with the MS and the N BSs via a cellular communication system. The cellular communication system includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a base station (BS) comprises an input and a channel estimation module. The input that receives signals from mobile stations (MSs). One of the signals having a direct channel gain (direct channel) is transmitted by one of the MSs associated with the BS. Others of the signals having interference channel gains (interference channels) are transmitted by others of the MSs associated with neighboring (N−1) BSs, where N is an integer greater than 1. The BS and the (N−1) BSs provide N BSs. Each of the N BSs uses at least N pilot values to communicate with the MS and the MSs. The channel estimation module generates channel estimates of the direct channel and the interference channels based on the N pilot values when one of the MSs is associated with the BS.

In another feature, the N pilot values are generated by the N BSs based on sequences having a non-zero cross-correlation.

In another feature, the channel estimation module generates a first matrix based on the signals, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the channel estimation module generates a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the channel estimation module generates a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the BS further comprises an interference suppression module that suppresses inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the other signals interfere with the signal.

In another feature, the BS further comprises antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and that receive the signals via at least one of the antennas.

In another feature, the MSs and the N BSs communicate via a cellular communication system that includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a method comprises receiving a signal having a direct channel gain (direct channel) from a mobile station (MS) via an input of a base station (BS). The MS is associated with the BS. The method further comprises receiving signals having interference channel gains (interference channels) from MSs other than the MS via the input. The MSs are associated with (N−1) BSs other than the BS, where N is an integer greater than 1. The BS and the (N−1) BSs provide N BSs. Each of the N BSs uses at least N pilot values to communicate with the MS and the MSs. The method further comprises generating channel estimates of the direct channel and the interference channels based on the N pilot values when the MS is associated with the BS.

In another feature, the method further comprises generating the N pilot values based on sequences having a non-zero cross-correlation.

In another feature, the method further comprises generating a first matrix based on the signal received from the MS and based on the signals received from the MSs, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the method further comprises generating a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the method further comprises generating a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the method further comprises suppressing inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the signals received from the MSs interfere with the signal received from the MS.

In another feature, the method further comprises providing antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and receiving the signal from the MS and the signals from the MSs via at least one of the antennas.

In other features, the method further comprises communicating with the MS, the MSs, and the N BSs via a cellular communication system. The cellular communication system includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple

Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a base station (BS) comprises input means for receiving signals from mobile stations (MSs). One of the signals having a direct channel gain (direct channel) is transmitted by one of the MSs associated with the BS. Others of the signals having interference channel gains (interference channels) are transmitted by others of the MSs associated with neighboring (N−1) BSs, where N is an integer greater than 1. The BS and the (N−1) BSs provide N BSs. Each of the N BSs uses at least N pilot values to communicate with the MS and the MSs. The BS further comprises channel estimation means for generating channel estimates of the direct channel and the interference channels based on the N pilot values when one of the MSs is associated with the BS.

In another feature, the N pilot values are generated by the N BSs based on sequences having a non-zero cross-correlation.

In another feature, the channel estimation means generates a first matrix based on the signals, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the channel estimation means generates a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the channel estimation means generates a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the BS further comprises interference suppression means for suppressing inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the other signals interfere with the signal.

In another feature, the BS further comprises antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and that receive the signals via at least one of the antennas.

In another feature, the MSs and the N BSs communicate via a cellular communication system that includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

In still other features, a computer program stored on a computer readable medium and executed by a processor comprises receiving a signal having a direct channel gain (direct channel) from a mobile station (MS) via an input of a base station (BS). The MS is associated with the BS. The computer program further comprises receiving signals having interference channel gains (interference channels) from MSs other than the MS via the input. The MSs are associated with (N−1) BSs other than the BS, where N is an integer greater than 1. The BS and the (N−1) BSs provide N BSs. Each of the N BSs uses at least N pilot values to communicate with the MS and the MSs. The computer program further comprises generating channel estimates of the direct channel and the interference channels based on the N pilot values when the MS is associated with the BS.

In another feature, the computer program further comprises generating the N pilot values based on sequences having a non-zero cross-correlation.

In another feature, the computer program further comprises generating a first matrix based on the signal received from the MS and based on the signals received from the MSs, a second matrix based on the N pilot values, and a third matrix that is a complex conjugate of the second matrix.

In other features, the computer program further comprises generating a fourth matrix that is a pseudo-inverse of the second matrix and a fifth matrix that is a product of the first and fourth matrices. The fifth matrix includes the channel estimates.

In other features, the computer program further comprises generating a fourth matrix that is a product of a noise variance and an identity matrix that is of the same order as the second matrix, a fifth matrix that is a product of the second and third matrices, a sixth matrix that is a sum of the fourth and fifth matrices, a seventh matrix that is a product of the first and third matrices, and an eighth matrix by dividing the seventh matrix by the sixth matrix. The eighth matrix includes the channel estimates.

In other features, the computer program further comprises suppressing inter-cell co-channel interference (interference) based on the channel estimates. The interference is generated when the signals received from the MSs interfere with the signal received from the MS.

In another feature, the computer program further comprises communicating with antennas that are arranged in a multiple-input multiple-output (MIMO) configuration and receiving the signal from the MS and the signals from the MSs via at least one of the antennas.

In other features, the computer program further comprises communicating with the MS, the MSs, and the N BSs via a cellular communication system. The cellular communication system includes one of an Orthogonal Frequency Division Multiplexing Access (OFDMA) system, a Code Division Multiple Access (CDMA) system, and a Worldwide Interoperability for Microwave Access (WiMAX) system.

Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the disclosure, are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1**A is a schematic representation of an exemplary cellular communication system comprising three base stations and a mobile station according to the prior art;

FIG. **1**B is a functional block diagram of an exemplary base station utilized in the system of FIG. **1**A;

FIG. **1**C is a functional block diagram of an exemplary mobile station utilized in the system of FIG. **1**A;

FIGS. **2**A and **2**B show examples of pilot values that may be used by base stations;

FIG. **3** shows an example of estimating a direct channel;

FIGS. **4**A and **4**B show an exemplary system for estimating direct and interference channels according to the present disclosure;

FIG. **5** is a flowchart of an exemplary method for estimating direct and interference channels according to the present disclosure;

FIG. **6**A is a functional block diagram of a vehicle control system;

FIG. **6**B is a functional block diagram of a cellular phone; and

FIG. **6**C is a functional block diagram of a mobile device.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is in no way intended to limit the disclosure, its application, or uses. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical or. It should be understood that steps within a method may be executed in different order without altering the principles of the present disclosure.

As used herein, the term module refers to an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

In cellular systems comprising base stations (BSs) that use pilot values generated using pseudo-random noise (PN) sequences having low-cross-correlation, mobile stations (MSs) can suppress inter-cell co-channel interference by estimating channels of signals received from all BSs. Specifically, when the MS is associated with the serving BS, the interference may be suppressed by estimating the direct channel (i.e., the channel gain of signals received from the serving BS) and all the interference channels (i.e., the channels or channel gains of signals received from all the neighboring BSs).

The MS may effectively suppress the interference when the number of pilot values used by the BSs is greater than or equal to the number of BSs and when the channel over all the pilot values is almost unchanged. The MS may estimate the direct and interference channels based on the pilot values, which are known to the MS.

The detailed description is organized as follows. First, a few examples of pilot values are discussed. Next, a mathematical model for input signals received by the MS is enumerated. Using the mathematical model, direct channel estimation is mathematically described followed by a numerical example. Subsequently, a matrix model for the input signals is proposed. Using the matrix model, two schemes for estimating direct and interference channels are discussed. Finally, exemplary applications of the schemes are discussed. A downlink (i.e., BS to MS communication) of a cellular system is used as an example only. The schemes are applicable to uplinks (i.e., MS to BS communications) as well.

Referring now to FIGS. **2**A and **2**B, examples of pilot values are shown. In FIG. **2**A, the MS may communicate with BS**1**, BS**2**, and BS**3**. BS**1**, BS**2**, and BS**3** may use pilots P**1**, P**2**, and P**3**, respectively. Although only three pilots are shown, additional pilots may be used. The pilots P**1**, P**2**, and P**3** are orthogonal since the cross-correlation between any two pilots is zero. Since the number of pilots is at least equal to the number of BSs, the MS may estimate one direct channel and two interference channels based on the pilot values shown.

In FIG. **2**B, the MS may communicate with BS**1** and BS**2**. BS**1** and BS**2** may use pilots P**1** and P**2**, respectively. Although only three pilots are shown, additional pilots may be used. The pilots P**1** and P**2** are orthogonal since the cross-correlation between them is zero. Since the number of pilots is at least equal to the number of BSs, the MS may estimate one direct channel and one interference channel based on the pilot values shown.

To understand channel estimation, a signal received by the MS may be mathematically represented as follows.

$$y_r[k] = \sum_{i=1}^{I} h_{r,i}\, p_i[k] + z_r[k]$$

where r is an antenna index, r=1, 2, . . . , N_R, and N_R is the total number of receive antennas of the MS; i is a BS index, i=1, 2, . . . , I, and I is the total number of BSs; and k is a pilot index, k=1, 2, . . . , K, and K is the total number of pilots. $y_r[k]$ is a receive signal received by r^{th} receive antenna. $h_{r,i}$ is channel gain of the signal received by r^{th} antenna from i^{th} BS. $h_{r,i}$ is shown to be independent of the pilot index k since the pilots will not be orthogonal if the channel gain changes over K pilots. Theoretically, pilots can be so generated that the channel gain may change only slightly over K pilots. Practically, however, when channel gain changes, system performance may degrade proportionally. $p_i[k]$ is a transmit signal transmitted by i^{th} BS at k^{th} pilot. The normalized total energy of the transmit signal transmitted by each BS over K pilots is given by

$$\sum_{k=1}^{K} |p_i[k]|^2 = 1 z_r[k]$$

is independent and identically distributed (iid) complex Gaussian noise with zero mean and variance.

Using the mathematical representation of the receive signal, a channel estimate of the direct channel may be mathematically expressed as follows.

$$\hat{h}_{r,1} = \sum_{k=1}^{K} p_1^*[k]\, y_r[k]$$

where i=1 indicates that BS**1** is the serving BS, and $p_i^*[k]$ is a complex conjugate of the transmit signal transmitted by BS**1** at k^{th} pilot. The channel estimate of the direct channel is a correlation of the received signal $y_r[k]$ received by the MS and the complex conjugate of the transmit signal transmitted by BS**1** at k^{th} pilot. The MS may generate the complex conjugate based on the pilot values used by BS**1**, which are known to the MS.

Referring now to FIG. **3**, an example of estimating the direct channel follows. For simplicity, let N_r=1, and K=3. The MS may receive signals y[1], y[2], and y[3]. When BS**1** is the serving BS, y[2]=0 and y[3]=0. The channel estimate of the direct channel for BS**1** is:

$$h_1\hat{}(1)=\Sigma p_1^*[k]y[k] \text{ for } k=1 \text{ to } 3$$

$$h_1\hat{}(1)=(-1)y[1] \text{ since } y[2]=0 \text{ and } y[3]=0$$

where $y[1]=(-1)\, h_1(1)$+noise

Accordingly, $h_1\hat{}(1)=h_1(1)$−noise

When the pilots are orthogonal, the interference due to signals transmitted by BSs other than the serving BS will be

zero during direct channel estimation. When the pilots are not orthogonal, however, the interference will be not be zero and may affect the direct channel estimate. To suppress the interference, the MS may estimate the interference channels in addition to estimating the direct channel.

To understand channel estimation of the direct and interference channels, the signal received by the MS may be expressed in matrix form as follows.

$$Y=PH+Z$$

where

$$Y=\begin{bmatrix} y_1[1] & y_2[1] & \cdots & y_{N_R}[1] \\ y_1[2] & y_2[2] & \cdots & y_{N_R}[2] \\ \vdots & \vdots & \ddots & \vdots \\ y_1[K] & y_2[K] & \cdots & y_{N_R}[K] \end{bmatrix}$$

$$P=\begin{bmatrix} p_1[1] & p_2[1] & \cdots & p_{N_R}[1] \\ p_1[2] & p_2[2] & \cdots & p_{N_R}[2] \\ \vdots & \vdots & \ddots & \vdots \\ p_1[K] & p_2[K] & \cdots & p_{N_R}[K] \end{bmatrix}$$

$$H=\begin{bmatrix} h_{1,1} & h_{2,1} & \cdots & h_{N_R,1} \\ h_{1,2} & h_{2,2} & \cdots & h_{N_R,2} \\ \vdots & \vdots & \ddots & \vdots \\ h_{1,I} & h_{2,I} & \cdots & h_{N_R,I} \end{bmatrix} \text{ and}$$

$$Z=\begin{bmatrix} z_1[1] & z_2[1] & \cdots & z_{N_R}[1] \\ z_1[2] & z_2[2] & \cdots & z_{N_R}[2] \\ \vdots & \vdots & \ddots & \vdots \\ z_1[K] & z_2[K] & \cdots & z_{N_R}[K] \end{bmatrix}$$

The MS generates the matrix Y based on the signals received from all the BSs (i.e., the serving BS and all the neighboring BSs). The MS generates the matrix P based on the known pilot values P used by all the BSs. Based on the matrices Y and P, the MS can generate the channel gain matrix H that includes the channel gains of the direct and interference channels. The MS may estimate the direct and interference channels with or without having information about noise.

Specifically, the MS may use one of two channel estimation schemes to estimate the direct and interference channels: zero forcing (ZF) based channel estimation and minimum mean square error (MMSE) based channel estimation. The ZF-based channel estimation estimates the direct and interference channels without noise information, while the MMSE-based channel estimation estimates the direct and interference channels using noise information. The MS may use the ZF-based channel estimation when noise information is unknown. The MS may use the MMSE-based channel estimation system when noise can be known or estimated.

Referring now to FIGS. **4**A-**4**B, a system for the estimating direct and interference channels and suppressing the interference according to the present disclosure is shown. In FIG. **4**A, a physical layer (PHY) module **100** of the MS receives input signals transmitted by the BSs (not shown) from an antenna **102**. When the MS associates with the serving BS, the input signals may include signals having direct and interference channels that are transmitted by the serving BS and the neighboring BSs, respectively. Although only one antenna is shown, the PHY module **100** may receive signals from multiple antennas. The antennas may be arranged in a multiple-input multiple-output (MIMO) configuration.

The system comprises a channel estimation module **104**, a pilot value lookup table **106**, a noise measuring module **108**, and an interference suppression module **109**. When the MS is associated with the serving BS, the channel estimation module **104** estimates the direct and interference channels using ZF-based and/or MMSE-based channel estimation schemes. The pilot value lookup table **106** stores the pilot values used by the BSs to transmit signals that may be received by the PHY module **100**. The noise measuring module **108** measures noise and selectively provides information about noise to the channel estimation module **104**. The interference suppression module **109** suppresses the interference based on the direct and interference channel estimates generated by the channel estimation module **104**.

The channel estimation module **104** comprises a control module **110**, a signal matrix generator module **112**, a pilot matrix generator module **114**, a complex conjugate module **116**, a pseudo-inverse matrix generator module **118**, and a matrix multiplication module **120**. The control module **110** determines whether to generate the channel estimates using ZF-based and/or MMSE-based channel estimation schemes based on input received from the noise measuring module **108**.

The control module **110** selects the MMSE-based channel estimation scheme when noise variance is known. When the MMSE-based channel estimation scheme is selected, the control module **110** may deselect the pseudo-inverse matrix generator module **118** and generate the channel estimates using the MMSE-based channel estimation scheme. The ZF-based and MMSE-based channel estimation schemes are now described in turn.

The channel estimates of the direct and interference channels generated using the ZF-based channel estimation scheme may be mathematically represented by the following equation.

$$\hat{H}=P^{+}Y$$

$$P^{+}=(P^{*}P)^{-1}P^{*}$$

where P^{+} is a pseudo-inverse matrix of the matrix P, and P^{*} is the complex conjugate matrix of the matrix P.

The signal matrix generator module **112** communicates with the antenna **102** and generates the matrix Y based on the input signals received by the antenna **102** from the BSs. The pilot matrix generator module **114** generates the matrix P based on the pilot values stored in the pilot value lookup table **106**. The complex conjugate module **116** generates the matrix P^{*}. The pseudo-inverse matrix generator module **118** generates the matrix P^{+}. The matrix multiplication module **120** multiplies the matrices P^{+} and Y to generate the matrix $\hat{H}$ that includes the channel estimates of the direct and interference channels.

When the pilots are generated using orthogonal PN sequences, $P^{*}P$ is an identity matrix, $P^{+}=P^{*}$, and $\hat{H}=P^{*}Y$. In other words, the ZF-based channel estimation reduces to estimating only the direct channel, and the channel estimates of the interference channels are not generated.

The channel estimates of the direct and interference channels generated using the MMSE-based channel estimation scheme may be mathematically represented by the following equation.

$$\hat{H}=(P^{*}P+\sigma^{2}_{N}I)^{-1}P^{*}Y$$

where σ_{N}^{2} is noise variance.

In FIG. **4**B, the control module **110** comprises a noise variance generator module **122**, a ZF/MMSE selection module **124**, a noise variance matrix generator module **126**, a matrix addition module **128**, and a matrix divider module **130**. The noise variance generator module **122** generates the noise variance information based on input received from the noise measuring module **108**. The noise measuring module **108** measures noise (e.g., white noise) based on inputs received from one or more gain stages (not shown), input signals received by the antenna **102**, etc. The noise variance may be known before channel estimation. When the noise variance is known, the ZF/MMSE selection module **124** generates a control signal that deselects the ZF-based channel estimation scheme and selects the MMSE-based channel estimation scheme to estimate the direct and interference channels.

Specifically, when the noise variance is known, the control module **110** deselects the pseudo-inverse matrix generator module **118**. The noise variance matrix generator module **126** generates a noise variance matrix ($\sigma_N^2 I$) by multiplying an identity matrix I having the same order as the order of the matrix P by the noise variance σ_N^2. The matrix addition module **128** adds the matrices (P*P) and ($\sigma_N^2 I$). The matrix divider module **130** divides the matrix (P*Y) by the sum of the matrices (P*P) and ($\sigma_N^2 I$) to generate the matrix $\hat{H}$ that includes the channel estimates of the direct and interference channels.

When the pilots are generated using orthogonal PN sequences, P*P is an identity matrix, and the matrix $\hat{H}$ is given by the following equation.

$$\hat{H} = \frac{1}{1+\sigma_N^2} P^* Y$$

In other words, the matrix $\hat{H}$ is equal to matrix (P*Y) having a scaling factor of ($1/(1+(\sigma_N^2))$). When $\sigma_N^2=0$, the MMSE-based channel estimation reduces to the ZF-based channel estimation. The accuracy of the noise variance information determines whether the channel estimates generated by the ZF-based channel estimation scheme are more or less accurate than the channel estimates generated by the MMSE-based channel estimation scheme.

Referring now to FIG. **5**, a method **150** for generating channel estimates of the direct and interference channels and suppressing the interference according to the present disclosure is shown. The method **150** begins at step **152**. When the MS is associated with the serving BS, the signal matrix generator module **112** generates the matrix Y in step **154** based on input signals received by the antenna **102** from the serving and neighboring BSs. The pilot matrix generator module **114** generates the pilot matrix P in step **156** based on the pilot values stored in the pilot value lookup table **106**. The complex conjugate module **116** generates the complex conjugate matrix P in step **158**. The matrix multiplication module **120** generates the matrices P*P and P*Y in step **160**.

The control module **110** determines in step **162** whether the noise information is known. If the result of step **162** is false, the pseudo-inverse matrix generator module **118** generates the pseudo-inverse matrix P^+ in step **164**. The matrix multiplication module **120** multiplies the matrices P^+ and Y in step **166** to generate the matrix $\hat{H}$ that includes the channel estimates of the direct and interference channels. The interference suppression module **109** suppresses the interference in step **167** based on the channel estimates of the direct and interference channels. The method **150** ends in step **168**.

If, however, the result of step **162** is true, the ZF/MMSE selection module **124** generates a control signal that selects the MMSE-based channel estimation scheme by deselecting the pseudo-inverse matrix generator module **118** in step **169**. The noise variance generator module **122** generates noise variance σ_N^2 in step **170** based on the input received from the noise measuring module **108**. The noise variance matrix generator module **126** generates the matrix ($\sigma_N^2 I$) in step **172** by multiplying the identity matrix I having the same order as the order of the matrix P by the noise variance σ_N^2. The matrix addition module **128** adds the matrices (P*P) and ($\sigma_N^2 I$) in step **174**. The matrix divider module **130** divides the matrix (P*Y) by the sum of the matrices (P*P) and ($\sigma_N^2 I$) in step **176** to generate the matrix $\hat{H}$ that includes the channel estimates of the direct and interference channels. The interference suppression module **109** suppresses the interference in step **167** based on the channel estimates of the direct and interference channels. The method **150** ends in step **168**.

The ZF-based and MMSE-based channel estimation schemes may be used to suppress inter-cell co-channel interference in cellular systems that use pilots and that have following characteristics. The pilots are generated by sequences having low cross-correlation. Different sequences may be used for neighboring BSs. Number of pilot values is at least equal to the number of BSs. Channel is almost unchanged over all the pilot values. Cellular systems having these characteristics include Orthogonal Frequency Division Multiplexing Access (OFDMA) systems, Code Division Multiple Access (CDMA) systems, and Worldwide Interoperability for Microwave Access (WiMAX) systems.

As an example, the ZF-based and MMSE-based channel estimation schemes may be used in WiMAX systems comprising BSs and MSs that are configured to operate in WiMAX wireless networks. WiMAX is a standards-based technology enabling wireless broadband access as an alternative to wired broadband like cable and DSL. WiMAX provides fixed, nomadic, portable, and mobile wireless connectivity without the need for a direct line-of-sight with a base station. WiMAX technology may be incorporated in portable electronic devices such as notebook computers, personal digital assistants (PDAs), etc.

Mobile WiMAX supports a full range of smart antenna technologies including beamforming, spatial multiplexing, etc., to enhance system performance. Mobile WiMAX supports adaptive switching between these options to maximize the benefit of smart antenna technologies under different channel conditions. Smart antenna technologies typically involve complex vector and matrix operations on signals due to multiple antennas. Typically, BSs may have at least two transmit antennas but may transmit preamble symbols via only one transmit antenna. MSs may have at least two receive antennas and may receive signals via more than one receive antenna.

In WiMAX systems, an MS can receive the pilot values from adjacent BSs by decoding preamble sequence and DL-MAP of the respective BSs. DL-MAP is a management message transmitted by the BSs in each frame. DL-MAP includes control information such as PN sequences used by the BSs to generate the pilot values. Adjacent BSs use identical sets of pilot values generated using PN sequences having low cross-correlation. Consequently, the pilot values used by the BSs are almost orthogonal.

The MS can learn the PN sequences used by the BSs by decoding the preamble sequence and the DL map of the serving and neighboring BSs. When the MS is closer to the serving BS than the neighboring BSs, the interference experienced by the MS due to signals transmitted by the neighboring BSs may be negligible. Accordingly, the MS may decode the preamble sequence and the DL-MAP of only the serving BS and not of the neighboring BSs.

Typically, the MS may experience considerable interference due to signals transmitted by at most two or three neighboring BSs depending on the position of the MS relative to the BSs. The number of pilot values used by the BSs is generally **120** per OFDM symbol (i.e., greater than 2 or 3 BSs). When the MS travels at a reasonable speed relative to the BSs, the channel over the pilot values shared by the BSs is almost unchanged. Accordingly, the MS can suppress the interference by estimating one direct channel and two or three interference channels using the ZF-based and/or MMSE-based channel estimation schemes.

The systems and methods for estimating direct and interference channel and suppressing the interference can also be used for uplink communications. For example, a cellular system may comprise three BSs (BS**1** to BS**3**) and three MSs (MS**1** to MS**3**). The three MSs may be associated with the three BSs, respectively. The three BSs may comprise the PHY module **100**. For uplink, all the MSs may transmit signals. All the signals may be received by each BS. A BS may, however, receive a signal from one MS that is stronger than the signals received from other MSs. For example, BS**1** may receive a signal from MS**1** that is stronger than the signals received from MS**2** and MS**3**. Accordingly, BS**1** may estimate the direct channel of the signal received from MS**1** and the interference channels of the signals received from MS**2** and MS**3** if three pilots are used. Generally, BS**1** can obtain the pilot values used by BS**2** and BS**3**, which serve MS**2** and MS**3**, respectively, by communicating with BS**2** and BS**3** through a backbone network.

Referring now to FIGS. **6**A-**6**C, various exemplary implementations incorporating the teachings of the present disclosure are shown. In FIG. **6**A, the teachings of the disclosure may be implemented in a network interface **252** of a vehicle **246**. The vehicle **246** may include a vehicle control system **247**, a power supply **248**, memory **249**, a storage device **250**, and the network interface **252**. The network interface **252** may include an interface for communicating with cellular systems such as OFDMA, CDMA, or WiMAX systems. The network interface **252** may include multiple antennas (not shown).

The vehicle control system **247** may be a powertrain control system, a body control system, an entertainment control system, an anti-lock braking system (ABS), a navigation system, a telematics system, a lane departure system, an adaptive cruise control system, etc. The vehicle control system **247** may communicate externally with different network systems using the network interface **252**.

The vehicle control system **247** may communicate with one or more sensors **254** and generate one or more output signals **256**. The sensors **254** may include temperature sensors, acceleration sensors, pressure sensors, rotational sensors, airflow sensors, etc. The output signals **256** may control engine operating parameters, transmission operating parameters, suspension parameters, etc.

The vehicle control system **247** may store data in memory **249** and/or the storage device **250**. Memory **249** may include random access memory (RAM) and/or nonvolatile memory such as flash memory, phase change memory, or multi-state memory, in which each memory cell has more than two states. The storage device **250** may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The power supply **248** provides power to the components of the vehicle **246**.

In FIG. **6**B, the teachings of the disclosure can be implemented in a cellular network interface **267** of a cellular phone **258**. The cellular phone **258** may include a phone control module **260**, a power supply **262**, memory **264**, a storage device **266**, the cellular network interface **267**, a network interface **268**, and a plurality of associated antennas (not shown). The cellular network interface **267** may include an interface for communicating with cellular systems such as OFDMA, CDMA, or WiMAX systems. The cellular phone **258** may include a microphone **270**, an audio output **272** such as a speaker and/or output jack, a display **274**, and a user input device **276** such as a keypad and/or pointing device.

The phone control module **260** may receive input signals from the cellular network interface **267**, the network interface **268**, the microphone **270**, and/or the user input device **276**. The phone control module **260** may process signals, including encoding, decoding, filtering, and/or formatting, and generate output signals. The output signals may be communicated to one or more of memory **264**, the storage device **266**, the cellular network interface **267**, the network interface **268**, and the audio output **272**.

Memory **264** may include random access memory (RAM) and/or nonvolatile memory such as flash memory, phase change memory, or multi-state memory, in which each memory cell has more than two states. The storage device **266** may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The power supply **262** provides power to the components of the cellular phone **258**.

In FIG. **6**C, the teachings of the disclosure can be implemented in a network interface **294** of a mobile device **289**. The mobile device **289** may include a mobile device control module **290**, a power supply **291**, memory **292**, a storage device **293**, the network interface **294**, an external interface **299**, and a plurality of associate antennas (not shown). The network interface **294** may include an interface for communicating with cellular systems such as OFDMA, CDMA, and WiMAX systems. The external interface **299** may include USB, infrared, and/or Ethernet.

The mobile device control module **290** may receive input signals from the network interface **294** and/or the external interface **299**. The input signals may include compressed audio and/or video, and may be compliant with the MP3 format. Additionally, the mobile device control module **290** may receive input from a user input **296** such as a keypad, touchpad, or individual buttons. The mobile device control module **290** may process input signals, including encoding, decoding, filtering, and/or formatting, and generate output signals.

The mobile device control module **290** may output audio signals to an audio output **297** and video signals to a display **298**. The audio output **297** may include a speaker and/or an output jack. The display **298** may present a graphical user interface, which may include menus, icons, etc. The power supply **291** provides power to the components of the mobile device **289**. Memory **292** may include random access memory (RAM) and/or nonvolatile memory such as flash memory, phase change memory, or multi-state memory, in which each memory cell has more than two states. The storage device **293** may include an optical storage drive, such as a DVD drive, and/or a hard disk drive (HDD). The

mobile device may include a personal digital assistant, a media player, a laptop computer, a gaming console, or other mobile computing device.

Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims.

What is claimed is:

1. A physical layer (PHY) device comprising:

a first module configured to (i) measure noise based on signals received by the PHY device via a channel, and (ii) generate information in response to measuring the noise based on the signals received by the PHY device via the channel; and

a second module configured to determine, depending on whether the first module is able to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel, whether to estimate a gain of the channel using

(i) a first procedure to estimate the gain of the channel, or

(ii) a second procedure to estimate the gain of the channel.

2. The PHY device of claim **1**, further comprising a third module configured to select the first procedure to estimate the gain of the channel and deselect the second procedure to estimate the gain of the channel in response to the first module being able to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel.

3. The PHY device of claim **1**, further comprising a third module configured to select the second procedure to estimate the gain of the channel and deselect the first procedure to estimate the gain of the channel in response to the first module being unable to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel.

4. A mobile device comprising:

the PHY device of claim **1**; and

an antenna configured to receive the signals via the channel.

5. The mobile device of claim **4**, wherein the signals include:

a first signal received from a first base station with which the mobile device is associated, wherein the first signal has a first channel gain, and wherein the first signal is transmitted from the first base station using a plurality of pilot values; and

a second signal received from a second base station with which the mobile device is not associated, wherein the second signal has a second channel gain, and wherein the second signal is transmitted from the second base station using the plurality of pilot values.

6. The mobile device of claim **5**, further comprising a third module configured to decode the plurality of pilot values from a preamble sequence transmitted from the first base station or the second base station.

7. The mobile device of claim **5**, further comprising a third module configured to decode the plurality of pilot values from a downlink map transmitted from the first base station or the second base station.

8. The mobile device of claim **5**, wherein the PHY device further comprises a third module configured to generate, in response the first module being able to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel, based on the plurality of pilot values, estimates of the first channel gain and the second channel gain using the first procedure to estimate the gain of the channel.

9. The mobile device of claim **5**, wherein the PHY device further comprises a third module configured to generate, in response the first module being unable to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel, based on the plurality of pilot values, estimates of the first channel gain and the second channel gain using the second procedure to estimate the gain of the channel.

10. The mobile device of claim **5**, wherein the PHY device further comprises a third module configured to suppress interference due to the second signal based on estimates of the first channel gain and the second channel gain.

11. A method comprising:

attempting, at a physical layer (PHY) device, to (i) measure noise based on signals received by the PHY device via a channel, and (ii) generate information in response to measuring the noise based on the signals received by the PHY device via the channel; and

determining, depending on an ability of the PRY device to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel, whether to estimate a gain of the channel using

(i) a first procedure to estimate the gain of the channel, or

(ii) a second procedure to estimate the gain of the channel.

12. The method of claim **11**, further comprising selecting the first procedure to estimate the gain of the channel and deselecting the second procedure to estimate the gain of the channel in response to the PRY device being able to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel.

13. The method of claim **11**, further comprising selecting the second procedure to estimate the gain of the channel and deselect the first procedure to estimate the gain of the channel in response to the PHY device being unable to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel.

14. The method of claim **11**, further comprising:

receiving the signals via an antenna of a mobile device, wherein the mobile device comprises the PHY device, and wherein the PHY device communicates with the channel via the antenna.

15. The method of claim 14, wherein the signals include:

a first signal received from a first base station with which the mobile device is associated, wherein the first signal has a first channel gain, and wherein the first signal is transmitted from the first base station using a plurality of pilot values; and

a second signal received from a second base station with which the mobile device is not associated, wherein the second signal has a second channel gain, and wherein the second signal is transmitted from the second base station using the plurality of pilot values.

16. The method of claim 15, further comprising decoding the plurality of pilot values from a preamble sequence transmitted from the first base station or the second base station.

17. The method of claim 15, further comprising decoding the plurality of pilot values from a downlink map transmitted from the first base station or the second base station.

18. The method of claim 15, further comprising, in response the PHY device being able to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel:

generating, using the first procedure to estimate the gain of the channel, estimates of the first channel gain and the second channel gain based on the plurality of pilot values.

19. The method of claim 15, further comprising, in response to the PHY device being unable to (i) measure the noise based on the signals received by the PHY device via the channel and (ii) generate the information in response to measuring the noise based on the signals received by the PHY device via the channel:

generating, the second procedure to estimate the gain of the channel, estimates of the first channel gain and the second channel gain using based on the plurality of pilot values.

20. The method of claim 15, further comprising suppressing interference due to the second signal based on estimates of the first channel gain and the second channel gain.

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